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16. Abstract Despite the progress achieved in the field of aeronautic techniques, spinal pain engendered by piloting helicopters still constitutes a current pathology. Chief forms discussed are lumbalgia and pathology of the dorsal and cervical spine, their clinical and radiological signs and their origins.			
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VERTEBRAL PAIN IN HELICOPTER PILOTS

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Introduction

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More than 40 years ago the test pilot Maurice Claisse, after an endurance flight in a Breguet-Dorand helicopter, underlined the disagreeable character of the vibrations that run through the whole craft: "Shaken up in an uncomfortable seat for an hour of flight, the pilot hastens to land and get back to the hangar to take care of his stiff spots."

In spite of the immense technological progress achieved since the flight of the first "gyroplane" in 1907, this remark, reported by Vice-Admiral Jubelin, unfortunately remains largely applicable today.

The decrease in the stress and nuisances, and an improvement in pilot's-seat hygiene, have in fact not followed the technical perfecting of the craft, and thus actual occupational diseases have developed, created by the fact of flight itself, and on occasion by aeronautic practice.

These pathological manifestations and their relationship with piloting a helicopter have been much studied in France since 1950, the date when the first helicopters were used in formations by the French Air Force.

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Numerous works have been devoted to this topic, among which we must cite those of Missenard and Terneau (1957), Fabre and Graber (1959), Montagnard et al. (1961), Sliosberg (1962), and more recently those of Delahaye, Auffret, Seris, Gueffier, Metges, Colleau and Vettes.

We undertook a systematic clinical and radiological study of the entire flight personnel of the Rotary-Wing Aircraft Section of the Bretigny Flight Testing Center. This section includes 12 subjects whose ages run from 28 to 53, with an average of 38 years. The number of flight hours in helicopters varies from 400 to 7000 hours (average: 2600 hours).

Subjected to a strict weekly medical monitoring, most of them participating in weekly sports activities, these test pilots, engineers or flight mechanics present a good general physical condition, and their only functional symptomatology is spinal.

I. Clinical Study

1) On the clinical plane, lumbalgia is predominant, which can regularly take two forms, acute or chronic; most often both forms alternate in the same subject over time.

Frequency

The frequency found in our study is 8 out of 12 cases. Although a small sample cannot give rise to significant statistics, this figure joins those published by Montagnard et al. (60%) and Sliosberg (75%) for large series; the high percentage found by the latter is probably due to the fact that his study concerned pilots operating in North Africa and subjected to genuine overwork.

Circumstances of Appearance

All the authors agree on the existence of a delay in the

appearance of painful phenomena: 300 hours for Sliosberg and Von Gierke, 500 to 1000 hours for Montagnard and on the same order for Colleau.

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This interval seems at present to be longer (1000 to 1500 hours in our study), and is above all subject to very great individual variations. It is decreased by the presence of pre-existing spinal lesions or congenital anomalies. For this reason a pilot having a transitional anomaly of the lumbosacral hinge joint complained of lumbar pain as early as the 20th hour of flight.

As for the flight rhythm, this known factor in the maintenance of symptomatology, we found values close to those published in the literature. The thresholds favoring the appearance of painful phenomena average:

- 30 to 40 flight hours a month
- 3 to 4 hours a day
- 1 hour 30 minutes of flight at a time.

Symptomatology

a) Chronic Lumbalgia is the most frequent (7 out of 12 cases). Its picture is that of a low-intensity pain like fatigue, heaviness, discomfort, seated in the lumbar region or sometimes located lower (lumbosacralgia). It is median transverse, often predominant on one side, capable of irradiation towards the buttocks, the iliac crests and more rarely the groin in front. This development of an ache is governed by flights, aggravated by lifting efforts and long trips in cars, and alleviated by resting in decubitus and kinesitherapeutic sessions.

Sometimes examination reveals a discrete scoliotic antalgic attitude with stiffness and a slight paravertebral contraction. But most often statics are correct and examination reveals no dynamic signs: slight decrease in the Schobert index, slowness in readjustment of the lumbar segment.

b) Acute lumbalgia was found in 6 subjects, 5 of these on the basis of a chronic lumbalgia, in an isolated manner.

Its mode of development is variable: often one finds a progressive beginning without any precise initial strain but after a period of unaccustomed overwork or an appearance at two times, the pain not manifesting itself until several hours after flight. Sometimes the onset is abrupt but the strain or improper movements that set it off here are independent of aeronautic practice (gardening, sports, etc.).

These acute lumbalgias fit the classic picture: back strain consisting of a very lively, intense pain aroused by the slightest movement, limiting any change of position; this pain is seated in the lumbosacral region, often sharper on one side, but usually irradiating throughout the lumbar and buttocks region, and often even into the thighs.

Examination, which is rendered difficult by the intensity of the pain, reveals painful laterovertebral points at the level of the last discs, paravertebral contraction and especially cyphoscoliotic antalgic bending, which remains identical in different movements of the spine. Moreover, it presents a bilateral lumbar Lasegue's sign.

Given rest in decubitus, preferably on a hard surface, and anti-inflammatory and relaxant anti-pain treatment, evolution is as a rule favorable within a few days, but acute lumbalgia is often reproduced at variable intervals on the basis of chronic pain (5 out of 6 cases).

c) Finally, sciatica, a major complication of degenerative disc disease, was found in 2 cases, attacking pilots with over 4000 hours of flight who suffered from lumbalgia for several years. Out of 128 subjects performing intensive work, Sliosberg found 11 of these.

Clinical examination reveals direct or crossed antalgic bending, the classic points of Valleix and especially Lasegue's sign. Sciatica affects roots L5 or S1 without preference, often accompanied then by an abolition of the Achilles reflex. One notes in general the absence of major signs of a neurological deficit; one of our cases, however, manifested itself in the paralytic form of the L5 type due to a very voluminous hernia of the disc which required surgical intervention.

2. Dorsalgia

This classically involves more a discomfort or an ache rather than an actual pain, seated in the middle region of the back (D6-D7) and yielding to stretching movements of the torso. It is often associated with lumbar pain. Sliosberg and Colleau found around 40% of this. For our part, we found no true dorsalgia; this difference can be explained in part by the improvement /56-3 of the piloting position and the dorsal comfort of the seats, but especially by the fact that Colleau's study involved pilots of the Naval Air Force who carried a folded-up dinghy and its inflation bottle, with a total weight of 8 kg, on their backs. This harness constitutes an uncomfortable back-rest and one not well adapted to series-production seats. These limitations were still further accentuated by wearing a Mae West.

3. Cervicalgia

In his study Sliosberg notes that 30% of the subjects presented low, median cervical pain, sometimes irradiating towards the shoulder or upper arm and in that case taking the form of a cervico-brachial neuralgia. They are exceptionally isolated, most often associated with lumbalgia. Colleau found 2 cases (out of 29), and interpreted this decrease by an increase in visibility at the control panels of modern aircraft.

For our part, we found 1 case of acute repeated cervicalgia in a pilot with 7000 hours of flight, appearing in the classic aspect

torticollis with an intense muscular contraction and antalgic scoliosis: these acute episodes supervened on a chronic pain basis.

Other pilots reported only a discomfort in the back of the neck or the rest of the neck, aroused by extreme movements of the head with variable evolutionary rhythms. It is aggravated by wearing a helmet.

II. Radiological Study

We performed a complete radiological examination in standing position with 8 plates: cervical spine, dorsal and lumbar region front and profile, disc L5-S1 front and profile.

The results of this study are as follows:

1. At the Level of the Lumbar Spine

-- on the level of vertebral statics: 2 cases of scoliotic stance

-- 2 cases of transitional anomalies with partial "disembedding" of the hinge-joint vertebra

-- in 5 pilots, signs of arthrosis were noted, essentially consisting of a marginal anterior osteophytosis affecting the vertebral bodies from L2 to L5, with a certain predominance in the 3 last vertebrae.

This osteophytosis was accompanied in 2 cases by an interlinear pinching L4-L5, one of which probably corresponds to a post-operative aspect (treatment of hiatal hernia).

The radioclinical correlations were relatively satisfactory in this group (4 out of 5 suffered lumbalgia), as well as for those

pilots who had a transitional anomaly; in this latter case an elective predisposition has long been assumed with respect to degenerative, traumatic or microtraumatic conditions (De Seze).

On the other hand, in two cases of confirmed lumbalgia, one of them a severe complicated form of sciatica, there was no radiological correspondence. This fact is not surprising, since in all the large collections of statistics that have been published it appears that at least 25% of cases of lumbalgia and sciatica give no radiological signs on standard plates (G. Vignon).

Finally, since the works of Delahaye, Metges, Mangin and Gueffer, which showed the existence of a scoliotic attitude in 20% of the so-called "normal" population, it seems that this isolated trouble with statics in the frontal plane cannot be recognized as a sign of pathological manifestation outside cases in which one is dealing with a bending of antalgic origin with paravertebral contraction.

2. At the Level of the Dorsal Spine

Discrete signs of arthrosis were found in 6 cases, essentially consisting of a marginal anterior osteophytosis affecting the vertebral bodies from D8 to D11, with a predominance for D9-D10, most often associated with a lumbar condition.

Troubles with frontal statics for which the preceding reservations remain valid were found three times, without clinical correlations.

3. At the Level of the Cervical Spine

In all subjects examined, deformations were found of the arthrotic type, in the unciform apophyses of C5-C6, and to a lesser degree C7, associated in C5 with trouble with sagittal statics of the rectitude type on the profile plate. Also found

was a marginal anterior osteophytosis C5-C6 (in two cases) and a pinching of the interline C6-C7 (1 case). In the only pilot who reported significant antecedents of cervicalgia, one found signs of a discarthritic type with a pinching of the interlines C5-C6 and C6-C7, an anterior marginal osteophytosis C5-C6-C7 and a posterior one C6-C7.

It is presently assumed that cervical arthrosis represents an anatomoradiological entity whose appearance may occur very early and whose extreme frequency after age 40 (50% of the population) contrasts with its clinical incidence, which is often absent or at least intermittent. However, the presence of identical radiological signs in all the pilots examined, most of whom were under 40, seems significant to us.

III. Physiopathological Approach

All studies performed up to now agree on the assumption that spinal pathology in helicopter pilots is the result of the synergic action of two factors:

- a postural factor: the bad piloting position,
- a microtraumatic mechanical factor due to the vibrations of the helicopter.

1. The Postural Factor

Well described by Sliosberg, it results from the fact that piloting a helicopter requires constant and coordinated use of all four limbs. The upper right limb manipulates the cyclic pitch control responsible for transverse motion, the upper left limb acts on the collective pitch lever that regulates the altitude of the vehicle, and finally the feet work the rudder bar which, by way of the tail rotor (anti-couple rotor) allows one to turn the machine and chose a flight course.

The placement of the collective pitch control requires the

pilot to lean to the left, while the visual requirements for flight necessitate a forward bending of the body, the head being hyper-extended. One can easily imagine that such a position runs against all comfort criteria established to date; Swearingen and Wisner have defined the value of the angles that have to exist among adjacent skeletal elements in order to allow, in a seated individual, a good relaxation of opposed muscle groups -- a physiological translation of the subjective notion of comfort.

These values differ notably from those measured in pilots, especially in craft with older designs (Sikorsky H 34 for instance).

This dissymmetrical and permanent attitude is thus going to engender a tonic contraction of the paravertebral and support muscles of the spine.

Now, as the analogical models described by Dieckmann and Coermann show, the human body can be compared to a collection of suspended masses tied together by systems of springs and shock absorbers (intervertebral discs, ligaments, muscles). The muscles play the role of shock absorbers, limiting the movements of the skeleton and protecting in this way the intervertebral discs. When contracted, their efficacy will rapidly decrease with fatigue and this shock absorber will be strained, hence exposing vertebrae and discs to the harmful direct action of vibrations.

Moreover, Keegan has demonstrated that at the level of the lumbar spine, the sitting position wipes out lordosis [sic], the vertebral bodies tend to come closer together in front and the intervertebral space tends to gape open towards the back; the pressure on the cord increases (10 to 15 kg/cm², or 30% more than in a standing position) and the nucleus pulposus is pushed back towards the peripheral part of the annulus, and above all the innervated capsulo-ligamentary area.

Hence the vibrational microtraumas will affect a spine that

is already made more fragile and sensitized.

2. Vibrations

A result of the imperfect yield of any mechanical system in motion, vibrations represent, like heat, a degraded form of energy that the human operator recovers directly at his working post in the form of nuisances. Their universal character and ergonomic importance explain why numerous researchers have tried to determine their physiological and physiopathological effects (Coermann, Dieckmann, Wisner, Berthoz).

The aeronautics field is far from free of vibrational stresses, and in particular the helicopter, among all the means of transportation used, is one of those which engender the highest level of vibrations.

Major works have been devoted to measuring these phenomena and studying their action on flight personnel; among them one must cite those of Goldman, Von Gierke, Guignard, and in France those of Seris, Auffret, Demange, Vettes. /56-5

A. Origin and Measurement of Vibrations

The vibrations recorded on board helicopters are mechanical and aerodynamic in origin: they are described in the rectangular-coordinate reference system (X,Y,Z) connected to the human skeleton.

-- Vibrations of Mechanical Origin

-- Low in frequency, they are provoked by the main rotor turning at a frequency Ω and by the N blades of this rotor; the causes are multiple, but we consider the following to be some of the main ones:

* The operation of jointed devices (cyclic pitch,

jarring); connected to the technology of the craft itself, they engender vibrations with a frequency $N\omega$ mainly on the Z axis (seat-head).

- * The difference in drag between blades moving forward and those moving backwards.

- * Bad adjustment of the angle of incidence of one blade relative to the others, entailing a vibration of frequency Ω along the Z axis.

- * Possibly, a defect in the static equilibration of the blades (unbalancing) creating an oscillation with a frequency Ω perpendicular to the above one.

-- Medium- and high-frequency ones have as their origin:

- * The operation of the engines or turbines

- * The rotor with frequency ω and its N blades (frequency $N\omega$)

- * The mobile organs of transmission

-- Vibrations of Aeronautic Origin

Very low in frequency, these are due to the responses of the airframe to aerodynamic excitation and to the actions of the pilots via servos (Seris, Auffret). They are considerable in high- or low-speed manoeuvres, during flight over rugged landscape at low altitude, or in stationary flight close to the ground.

Measurement of the vibrations by spectral analysis or frequency analysis, which gives the distribution of the energies in play as a function of frequency, was performed at the Flight Testing Center for different types of helicopters. For each craft it

was possible to find two characteristic low-frequency peaks corresponding to (3.7 to 8.5 Hz) and N (15 to 20 Hz).

Although the first peak, due to defective adjustment, can be reduced considerably, the second, which is inherent to the operation of a helicopter, is inevitable.

The response of the human body to these vibrations was evaluated in flight by means of accelerometers placed on the seat and the main body masses. One can also study it in the laboratory, thanks to vibrating tables. The Aerospace Medicine laboratory has an electro-hydraulic vibration generator that can be operated either by a regular program (sinusoidal) or by a magnetic tape reproducing the vibrations recorded on board the aircraft.

B. Results

The physiological effects of vibrations are due to deformations and displacements which are relatively major, suffered by the organs or tissues at certain frequencies.

The studies of Dieckmann and later of Coermann make it possible, by means of simple analogical models, to study and explain the action of vibrations along axis Z upon the organism, and in particular on the spine.

These models allow one to take into account the existence for each segment of the body of a resonance frequency, that is, a frequency at which the transmission of the movement applied to the supporting structure is at a maximum. Above this frequency transmission decreases: there is a filter effect.

The physiopathological actions of vibrations thus depend on the resonance frequency of the different body masses and the frequency applied to the support structure.

The main resonance frequencies studied by Goldmann and Von /56-6

Gierke are: from 1 to 6 Hz for the thorax as a whole, from 12 to 14 Hz for the upper part of the thorax with forward bending of the spine, from 20 to 30 Hz for the head.

Overall, between 2 and 10 Hz the amplitude of the response is higher than that of the excitation; beyond this point it decreases. However, between 20 and 30 Hz, due to the fact of its resonance, the head has a vibration amplitude three times greater than the adjacent segment.

It is easy to see that all these values are on the same order as those of the vibrations recorded on board helicopters. The body masses which are vibrated in this way will undergo movements with relative independence, actively stressing the intervertebral discs and the paravertebral muscle masses that constitute the spring-shock absorber system.

It is important here to stress the role played by the seat in assuring the transmission of craft movements to the pilot. As a general rule, present seats increase vibrations up to a frequency of 10 - 15 Hz and then tend to damp them for higher frequencies. This amplification at low frequencies, sometimes considerable (ratio of 2.5 or more), will contribute to increase spinal stress.

In this respect, one must insist with Wisner and Berthoz on the importance of phase displacements, which different suspended masses may present among themselves and which would be especially harmful to the spine, in particular changes in phase between the thorax and the pelvis. In addition to these axial movements, the vibrations on the Z axis produce forward and backward oscillations in the vertebral column: between 12 and 14 Hz, for instance, the dorsal spine flexes forwards; this phenomenon is particularly clear at the level of the head, which responds to vertical stresses by horizontal oscillations.

One can easily imagine that this back and forth movement,

aggravated by a hyperextended position and wearing a helmet,, which adds a certain inertia to the system, can engender lesions at the level of the hinge-joint zone represented by the lower cervical spine.

The physiopathology of vibrations on the X and Y axes for the spine is less well known, but it is certainly far from negligible, acting by means of shear forces, often amplified here too by the seat cushion.

In sum, all these physiopathological data allow us to understand better the action mechanism of vibrations on a spine which is sensitized by bad posture. Once the muscular shock absorber has been strained, the overworking of the disco-ligamentary system will translate itself on the anatomical plane into the appearance of a degenerative discopathy, which is at the source of the clinical and radiological picture found.

IV. Prevention Means

As in all pathology of an occupational character, two simultaneous objectives should be pursued: to adapt the man to his work and the machine to its human operator.

In the question of helicopters, considerable progress can be determined in the matter of the vibration level in craft of the newer generation. This fact has been measured in the Gazelle, and could be appreciated subjectively by pilots in the Dauphin and Ecureuil, which are the latest products of French aeronautics production. This is due to technological refinements that make it possible to replace jointed metal systems with single-block parts made of plastic, plus the installation of shock absorbers ("cylind-blocks") which decrease the vibrations engendered by the rotors and their transmission in movement.

On the other hand, except for the Super-Frelon, for which

the piloting position is relatively satisfactory, progress still remains to be made in this field, as well as in the field of seats, which still all too often amplify low-frequency vibrations that are harmful to the spine.

One must note here, however, the improvement that has been achieved in the matter of postural comfort by the use of automatic stabilizers (Gazelle, Alouette III) and the automatic pilot (Puma, Super-Frelon).

In the matter of the adaptation of the man to his job, this must begin with a careful selection of future helicopter pilots, including a complete radiological examination of the spine in a standing position; this examination will allow one to eliminate right off subjects who present major static problems, transitional anomalies with total "disembedding" of the vertebral pivot, or very asymmetrical anomalies, certain other congenital anomalies or sequelae of acquired conditions (arthritis, osteoarthritis). It will then be necessary to be alert, during the course of the pilots' practice of aeronautics, to the matter of duration thresholds and flight rhythms which may favor the appearance of vertebral pain.

Finally, the observation of simple hygienic and dietary ^{/56-7} rules: healthy and balanced diet, regular practice of physical exercise (gymnastics, swimming in particular) will allow one to avoid a weight overload and a relaxing of the paravertebral musculature, sensitizing the spine to occupational microtraumas.

Here one must stress the role played, in counseling and surveillance, by the flight surgeon in the area of this individual level of prevention.

All these prophylactic measures must make it possible to avoid the appearance of inveterate painful phenomena with the socio-professional and psychological repercussions they entail -- this last capable of going so far as the neurosis described by Bergouignan in 1961 (lumbalgic neurosis).

Conclusion

Despite the progress achieved in the field of aeronautic techniques, spinal pain engendered by piloting helicopters still constitutes a current pathology.

On the functional level, lumbalgia remains the main subject of chronic complaints, interspersed with acute pangs, sometimes complicated with sciatica; its delay in appearance seems at present to have been prolonged, without a doubt due to the slowdown in flight rhythms. Radiologically it often translates into the presence of arthrotic signs, sometimes into the discovery of a predisposing congenital anomaly; and finally in a certain number of cases (30% for Delahaye) the standard radiological examination is normal.

Dorsal spinal pathology can be summarized as the presence in a not-insignificant percentage of cases (around 50%) of discrete signs of arthrosis, affecting electively D8-D9-D10; the clinical incidence is practically nil in the population studied.

Finally, in all the pilots examined, the existence was found of an arthrosis-type image of the unciform apophyses of C5-C6-C7, often associated with a cervical straightening in the sagittal plane.

These dorsal, and especially cervical, anomalies supervene with great frequency in relatively young subjects, and deserve to be taken into consideration. In previously published statistics, dorsalgias and cervicalgias found in pilots working under different conditions were more often connected to a paravertebral muscular contraction. It seems in fact that under the shadow of the lumbalgias, which remain on the first plane of the clinical picture, lesions can develop higher up in a precocious and insidious manner, located particularly in the cervical area, and appearing clinically only under special conditions (intensive flight, for instance).

Only a long-term clinical and radiological study involving repeated examinations under the same conditions can indicate in a precise manner the development of these lesions and their evolution relative to the general population.

The development of research in the field of the physiological and physiopathological effects of vibrations will no doubt also allow us to understand these problems better.

For the moment, one can only offer hypotheses.